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INTRODUCTION

One of the viable options of long-term geological disposal of the nuclear power reactors generated spent fuel is to extract plutonium, the minor actinides (MA) and potentially long-lived fission products from the spent fuel and transmute them into short-lived or stable radionuclides in an appropriate reactor for the reduction of the radiological toxicity of the nuclear waste stream. An important component of that technology will be a non-fertile / low-fertile actinide transmutation fuel form containing the plutonium, neptunium, americium (and possibly curium) isotopes to be transmuted. Such advanced fuel forms, especially ones enriched in the long-life minor actinide (LLMA) elements (i.e., Np, Am, Cm), have minimal irradiation performance data available from which to establish a transmutation fuel form design. Recognizing these needs, an Advanced Fuel Cycle test series-1 (AFC-1) irradiation test on a variety of candidate fuel forms is now being conducted in Advanced Test Reactor (ATR) at the Idaho National Laboratory (INL).

The first advanced fuel experiment (AFC-1) has been finalized and the test assembly analyzed for insertion and irradiation in ATR. The ATR core consists of a serpentine and rotationally symmetric fuel assembly about the z-axis of the core center. The plan view of the ATR core configuration is shown in Fig. 5, in Ref. 1. A cadmium filter with a 0.178 cm (0.045") thickness and 121.5 cm (48") in length, is currently used in the actinide-fuel capsule design for the East Flux Trap (EFT) position in ATR, to depress the linear heat generation rate (LHGR) lower than the project's 330 W/cm limit for the experimental fuel rodlets. The LHGR is proportional to the fission power deposited in the fuel rodlets from the neutron fissions. The fraction of the fission power generated from the neutron fission reactions deposited in the fuel rodlet is an important parameter for test assembly thermal analysis, which will be validated in this summary.

TEST ASSEMBLY MODEL DESCRIPTION

The AFC-1 model consists of six variants of transuranic (U, Pu, Am and Np) containing zirconium-based alloy fuels (AFC-1H) inserted in the E-2 position, six plutonium-zirconium-nitride-based fuel types (AFC-1G) inserted in the EFT E-3 position, and the metal-based AFC-1D fuel inserted in the E-1 position. Each fuel pin with 6 inches in length contains one rodlet. Nominal fuel rodlet length is 3.81 – 5.08 cm with all rodlets similar in size and appearance. Each test assembly contains 6 fuel pins (rodlets), axially designated as rodlet 1 through rodlet 6. The radial views of the fuel test assembly are shown in Fig. 1 of the ATR East flux trap position.

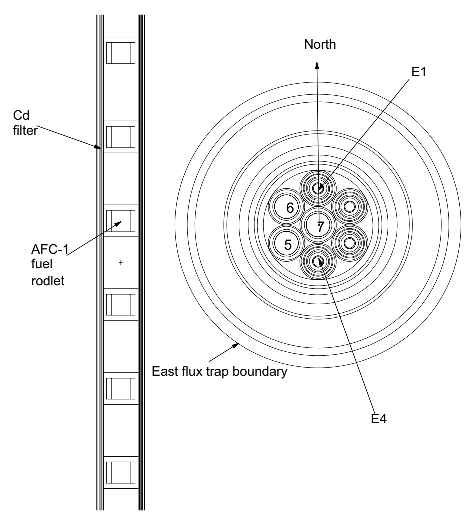

Fig. 1. X-Y view of AFC-1 test assembly arrangement in East flux trap position (Metal capsules in E-1 and E- 2 and Nitride capsules in E-3 and E-4 positions), and an axial view of the Metal capsule arrangement in the E-1 position for fuel test rodlets 1 to 6.

FISSION ENERGY DEPOSITION VALIDATION

The determination of the fission energy deposited into the fuel meat is important for the accurate assessment of the maximum value of the heat flux. In order to assess the value of the fission energy, which is deposited into the fuel meat, we must estimate the fraction of the gamma energy, leaving the fuel meat during the fission process.

MCNP[1] can only solve neutron-induced photon transport, the contribution from the delayed photons from the fission products can not be computed directly by the code. A separate geometry model of the fuel test assembly has been developed for evaluation of the heating from the delayed photons.

According to Ref. 3 and 4 (Table 1), the total energy released in the fission of one nucleus of ^{235}U by neutrons is 200 MeV. Of these fission release components, we assume that Kinetic energy of lights+ fission fragment, Kinetic energy of heavier fission fragment, and Beta particle energy gradually released from fission products are 100% deposited. While, the kinetic energy of fission neutrons is about 5 MeV, but, we assumed it has 0.0% deposited in the fuel rodlet. Therefore, we only need to calculated the fraction of the γ-ray energies (6+7+8=21 MeV) in Table I,[2,3] which would deposited in the fuel rodlet.

TABLE I. U^{235} Fission Energy Release.

Fission fragment kinetic energy	167
Fission products delayed β-energy	7
Fission neutron kinetic energy	5
Prompt gamma ray energy	6
Fission products delayed γ-energy	7
Excess neutrons radioactive capture	8
Total (MeV)	200

RESULTS AND DISCUSSION

To calculate the ratio of the fission heat source deposited locally, we developed an isolated East flux trap test loop model[4] with boundaries at the side, top and bottom of the test loop, which will make the photon source generated in the fuel rodlet either deposited in the fuel rodlet itself or the surrounding materials in the test loop. Using this model, MCNP can be used to calculate the photon energy deposition tally (F6:p-rodlet) in the fuel rodlet, which also can generate the photon spectrum. Next, to calculate all the neutron induced γ-heat source deposited in the fuel rodlet locally, we void all the surrounding materials in the model, except fuel rodlet, and model it with reflecting boundaries at the side, top and bottom of the test loop, which will make all the photon source generated in the fuel rodlets deposited in rodlet itself without any leakage. The MCNP-calculated photon energy deposition tally (F6:p- void) in the fuel rodlet in the void model represents the entire γ-heat source deposited in the fuel rodlet itself.

The MCNP-calculated results indicate that the ratio of the fission induced γ-heat source deposited locally is F6:p-roldlet / F6:p-void = 16%. As a result, the total escaped fission energy is 5 (Kinetic energy of fission neutrons) + 21(Total γ-ray energy) * (1.0 – 0.16) = 22.6 MeV per fissions, which represents 88.7% of fission energy deposited in the fuel rodlets.

CONCLUSIONS

For the advanced fuel test assembly best estimated thermal analysis, we have to know the fraction (ratio) of the fission induced secondary γ-heat source deposited in the fuel rodlet. Calculations have been performed for different fuel configurations and it was determined that only 15.57% from the γ-ray energy released during the fission process remains in the fuel rodlet. As a result, we conclude that the fraction of the fission energy deposited in the fuel rodlets are 88.63%. The same modeling approach can also be used in the other advanced fuel testing (AGR-1, AFC-2, and RERTR) programs.

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